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A STATISTICAL STUDY OF NORMAL LOAD FACTOR JUST PRIOR TO GROUND CONTACT FOR FIVE LIGHT AIRPLANES

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16. Abstract

The normal load factor just prior to ground contact has been determined from VGH records of 980 landings of five light airplanes. Frequency-distribution and probability curves have been fitted to the data samples for each airplane. The distributions of normal load factor just prior to ground contact had mean values ranging from 0.962 to 1.013 with standard deviations ranging from 0.039 to 0.074.

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A STATISTICAL STUDY OF NORMAL LOAD FACTOR JUST PRIOR TO GROUND CONTACT FOR FIVE LIGHT AIRPLANES

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SUMMARY

A statistical study of the values of normal load factor just prior to ground contact is presented for landings of five light airplanes. These data were obtained by measurements of normal acceleration from VGH records of a total of 980 landings of the five different types of light airplanes. Frequency-distribution curves and probability curves were fitted to the samples of data for each airplane.

The results indicate that the normal load factor just prior to ground contact varied from 0.70 to 1.20 for the total data sample of all five airplanes. The distributions of normal load factor for each airplane had mean values ranging from 0.962 to 1.013 with standard deviations ranging from 0.039 to 0.074. The probability that the normal load factor just prior to landing would be significantly less than 1.00 was greater for four of the five light airplanes than for the piston-engine transport airplanes of a previous study.

INTRODUCTION

In 1955, some NACA VGH data were used in a statistical study of wing lift at the instant of ground contact for four transport airplanes. (See ref. 1.) It was believed that these data would be useful in establishing a consistent ground-loads criterion relative to the value of lift force assumed to act on the airplane during the landing impact. For example, at that time the U.S. Air Force ground-loads design requirements assumed the lift force at ground contact to be equal to the weight of the airplane (ref. 2), whereas the civil regulations for transport-category airplanes (ref. 3) specified that this lift would not exceed two-thirds the weight of the airplane. The civil regulations for transport-category airplanes have since been changed (ref. 4); the lift at ground contact may now be assumed to be equal to the weight of the airplane. However, the present regulations for general-aviation-type airplanes (ref. 5) specify that the lift at ground contact may not exceed two-thirds the weight of the airplane.

A study similar to that reported in reference 1 has been made in order to provide information on airplane lift at the instant of ground contact for five general aviation airplanes. The present NASA V-G/VGH program to determine operational experiences of general aviation aircraft has provided flight time-history records of the normal acceleration at the center of gravity for several types of airplanes and operations. Some of these records have been evaluated to determine the airplane normal load factor just prior to ground contact for a total of 980 landings of five different types of light airplanes. These data are presented in this paper in the form of observed-frequency and cumulative-frequency distributions of normal load factor. Frequency-distribution curves and probability curves have been fitted to the samples of data for each airplane type. The probability curves are also compared with those given in reference 1 for four piston-engine transport airplanes.

SYMBOLS

a_z	incremental acceleration at airplane center of gravity
f_o	observed frequency in class interval
g	acceleration due to gravity
N	total observed frequency for one sample of data
n	normal load factor, $1 + \frac{a_z}{g}$
$\bar{n}$	mean value of normal load factor
Δn	class interval, equal to 0.05
α_3	coefficient of skewness
α_4	coefficient of kurtosis
σ	standard deviation

DESCRIPTION OF AIRPLANES AND OPERATIONAL USE

The airplanes used in this study are small general-aviation-type airplanes ranging from a 1500-pound (6672-newton), single-engine airplane with tail wheel and nonretractable landing gear to a 12 500-pound (55 600-newton), twin-jet, executive transport with retractable tricycle landing gear. Some of the characteristics of the five airplanes, which are identified as airplanes A, B, C, D, and E, are given in table I.

Airplane A belonged to a single owner and was used primarily for personal business flying. Airplane B belonged to a fixed-base operator and was used for charter flights which included some rough field operation while ferrying hunting parties into mountainous regions. Airplane C belonged to a company and was used as an executive transport. Airplane D belonged to a 21-member flying club and was operated by pilots with varying degrees of proficiency. Airplane E belonged to a single owner and was used in commercial fish-spotting operations.

DATA

Source

The NASA VGH program to determine operational experiences of general aviation aircraft has provided time histories of flight operations for the five airplanes described in the previous section. (See ref. 6.) From these time histories the airplane normal load factor just prior to landing has been determined for 147, 301, 210, 157, and 165 landings of airplanes A, B, C, D, and E, respectively.

VGH Recorder

The NASA VGH recorder, when installed in an airplane, provides a time history of airspeed, altitude, and vertical acceleration at the airplane center of gravity over a long time period (80 hours of operation per film drum). A description of the VGH recorder and the accuracy of measured quantities is given in reference 7. The static accuracy of the acceleration measurement is within 1 percent of full scale, and the maximum record-reading error is estimated to be ±0.03g.

Data Reduction

When the airplane is airborne with wings level, the normal acceleration at the center of gravity in g units is essentially equivalent to the ratio of airplane lift force to airplane weight and is referred to in this paper as normal load factor. The normal load factor is 1.0 for steady level flight where lift is equal to weight.

The time histories of load factor for three landings are shown in figure 1 to illustrate the VGH records and the method of record analysis used in this paper. Each example shows a relatively thick trace with low-frequency variations before landing contact, followed by a thin, sometimes barely visible trace with higher frequency variations after landing. The initial landing contact is indicated by the discontinuation of the thicker trace and an abrupt positive acceleration pulse. For example, the normal load factor just prior to landing contact is 0.99 for the landing shown in figure 1(a) and 1.07 for that shown in figure 1(c).

Landings having multiple impacts, such as shown in figure 1(b), occurred quite frequently (about one in four) for airplane B and very rarely for the other airplanes. For the landing shown in figure 1(b), the normal load factor is about 1.0 just before the first high-frequency pulse, and about 2 seconds later the thick trace shows a value of 0.87 for the normal load factor just prior to another large-magnitude, high-frequency positive pulse. This pulse, indicating final contact, is immediately followed by a sustained high-frequency variation indicative of ground vibration, whereas the thick trace between initial and final contact is indicative of airborne motion.

The multiple-impact landings evaluated for this paper were similar to the example of figure 1(b) in that there was at least 1 second between impacts and the normal load factor just prior to final contact was usually less than that prior to initial contact. The data presented in this paper represent final contact conditions because the lower normal load factors define more conservative landing-impact design conditions than the larger normal load factors generally associated with the initial contact.

FREQUENCY DISTRIBUTIONS

Data for 147 landings of airplane A, 301 landings of airplane B, 210 landings of airplane C, 157 landings of airplane D, and 165 landings of airplane E are summarized in table II in the form of frequency distributions of normal load factor n. The class interval $\Delta n = 0.05$ is used for these distributions. Also shown in table II are the following statistical parameters: mean value of normal load factor $\bar{n}$, standard deviation σ, coefficient of skewness α_3, and coefficient of kurtosis α_4. These parameters were calculated by methods described in chapter IV of reference 8. The significance of these parameters is briefly outlined in reference 1.

The distributions of normal load factor for each airplane are given in figure 2 as histograms showing the relative frequency f_o/N in each class interval. The frequency-distribution curves shown in figure 2 were fitted to the observed data by Pearson's system of frequency curves described in reference 9. From criteria given in reference 9, it was determined that the data sample for each airplane could be fitted by a Pearson type IV curve. Furthermore, it was found that the distributions for airplanes A, C, and D were essentially symmetrical and could be fitted with type VII curves. The type VII curve is a special case of the type IV curve and is more easily determined. Therefore, the distributions for airplanes A, C, and D were fitted with Pearson type VII curves, and those for airplanes B and E were fitted with type IV curves.

The observed and fitted distributions for all samples of data in figure 2 were integrated from both ends to determine the probability that the normal load factor would be greater than or less than a given value. These results are shown by the probability curves and data in figure 3. A comparison of the fitted probability curves for the five airplanes is shown in figure 4 along with a hatched band representing the curves for the four piston-engine transports reported in reference 1.

DISCUSSION

The results given in table II and figure 2 show that for all samples of data the value of normal load factor just prior to ground contact was within the range from 0.70 to 1.20. The five distributions of normal load factor just prior to ground contact had mean values ranging from 0.962 to 1.013 and values of standard deviation ranging from 0.039 to 0.074.

The data given in table II, frequency distributions shown in figure 2, and probability curves summarized in figure 4 show that the results for airplane B were significantly different from those for airplanes A, C, D, and E. The mean value of normal load factor just prior to ground contact was approximately 1.000 for all the landings of airplanes A, C, D, and E but was 0.962 for the landings of airplane B. The data for airplanes A, C, D, and E also showed much less variability than the data for airplane B, having standard-deviation values ranging from 0.039 to 0.051 compared with a value of 0.074 for airplane B. The difference between the data for airplane B and those for airplanes A, C, D, and E is shown most graphically by the fitted probability curves in figure 4.

One reason for the lower value of $\bar{n}$ for airplane B was the previously mentioned tendency for the landings of this airplane to have more than one impact, the value of n just prior to final impact (which was used in the data tabulations) usually being less than the value for initial impact. It is not known whether these multiple-impact landings were related to a particular pilot or to the rough field operation of this airplane.

The probability that the normal load factor just prior to ground contact will be less than a given value is important in assessing the rationality of landing-loads design requirements. The probability that the normal load factor will be greater than a given value is presented herein but appears to have little significance for design purposes.

As pointed out previously, the ground-loads design requirements specify for civil transports (ref. 4) that the lift during landing impact may not exceed the weight of the airplane and for general aviation airplanes (ref. 5) that this lift may not exceed two-thirds the weight of the airplane. Extrapolation of figure 4 indicates that for airplane B the probability was slightly less than 1 in 1000 that the normal load factor would be as low as 0.67 (lift equal to two-thirds of the airplane weight), and the probability was considerably less that the other four airplanes would have normal load factors as low as 0.67. Only the curve for airplane A was completely within the band representing the curves for the four piston-engine transports of reference 1. The probability that the normal load factor just prior to ground contact would be significantly less than 1.00 was greater for four of the five light airplanes in this study than for the transport airplanes in reference 1.

CONCLUDING REMARKS

The results of a statistical study of normal load factor during a large number of landings for five light airplanes showed that the normal load factor just prior to ground contact was within the range from 0.70 to 1.20. The five distributions of normal load factor just prior to ground contact had mean values ranging from 0.962 to 1.013 and values of standard deviation ranging from 0.039 to 0.074. The probability that the normal load factor just prior to landing would be significantly less than 1.00 was greater for four of the five light airplanes than for the piston-engine transport airplanes of a previous study.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., February 6, 1970.

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TABLE I.- AIRPLANE CHARACTERISTICS

Airplane	Maximum take-off weight		Propulsion	Wing span		Wing area		Stall speed, knots	Landing gear
	lb	N		ft	m	ft^2	m^2		
A	3 125	13 900	Single-engine reciprocating	33.46	10.20	181.00	16.81	52.0	Tricycle-type retractable
B	2 800	12 454	Single-engine reciprocating	36.17	11.02	174.00	16.16	50.5	Tail-wheel-type nonretractable
C	12 500	55 600	Two-engine turbojet	35.58	10.84	231.77	21.53	109.0	Tricycle-type retractable
D	2 575	11 454	Single-engine reciprocating	35.00	10.67	166.93	15.51	49.5	Tricycle-type retractable
E	1500	6 672	Single-engine reciprocating	35.25	10.74	178.50	16.58	39.0	Tail-wheel-type nonretractable

TABLE II.- FREQUENCY DISTRIBUTIONS AND STATISTICAL PARAMETERS

Normal load factor, n	Observed frequency f_o for airplane –				
	A	B	C	D	E
0.70 to 0.75	0	4	0	0	0
0.75 to 0.80	0	5	0	0	0
0.80 to 0.85	0	14	1	1	0
0.85 to 0.90	2	27	0	2	6
0.90 to 0.95	10	63	12	17	20
0.95 to 1.00	66	97	70	59	49
1.00 to 1.05	59	69	91	60	68
1.05 to 1.10	10	17	28	16	19
1.10 to 1.15	0	3	6	1	3
1.15 to 1.20	0	2	2	1	0
Total, N	147	301	210	157	165
$\bar{n}$	0.997	0.962	1.013	0.999	1.000
σ	0.039	0.074	0.048	0.048	0.051
α_3	-0.246	-0.567	0.248	-0.064	-0.280
α_4	3.427	4.013	4.476	4.289	3.719

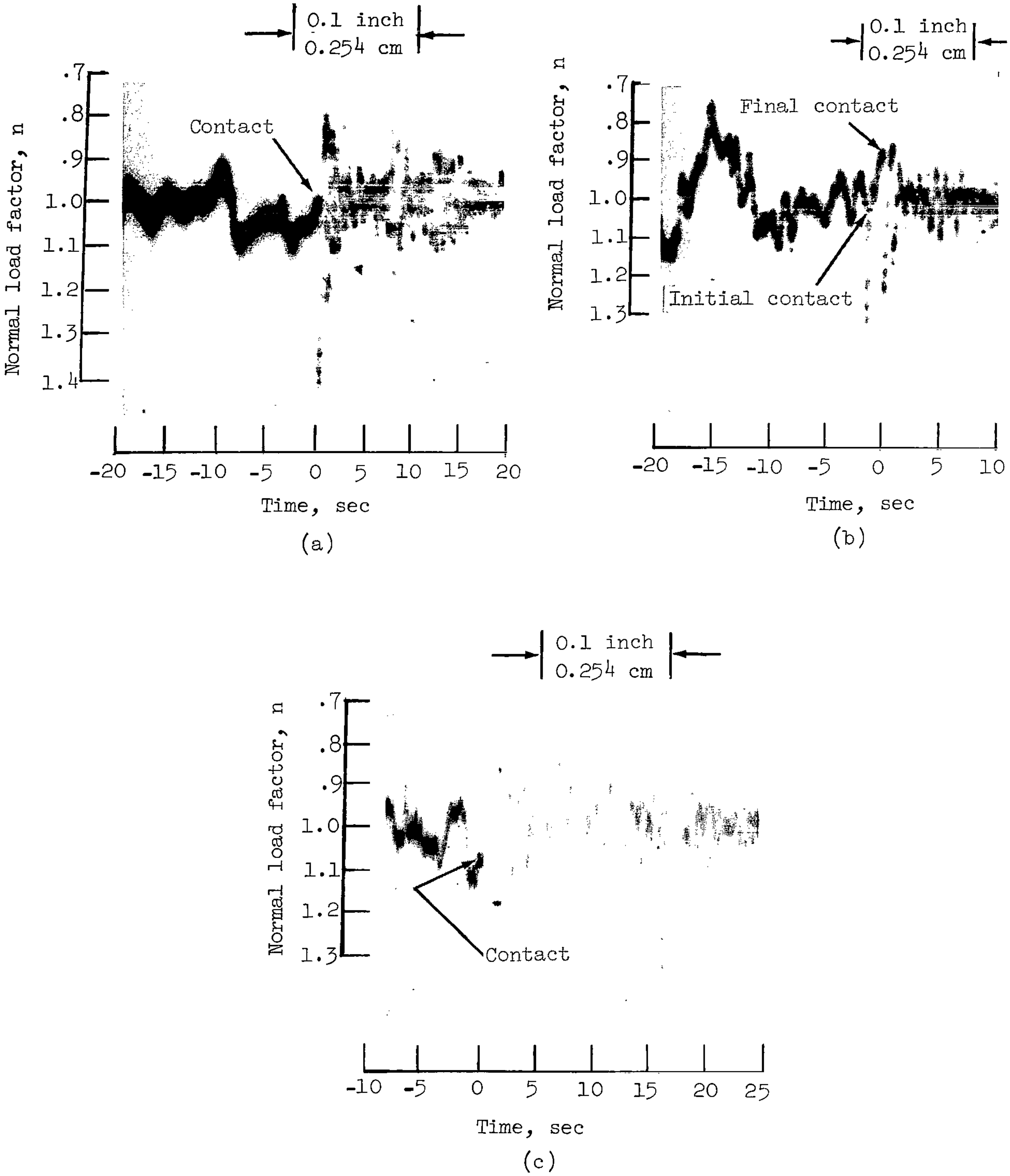
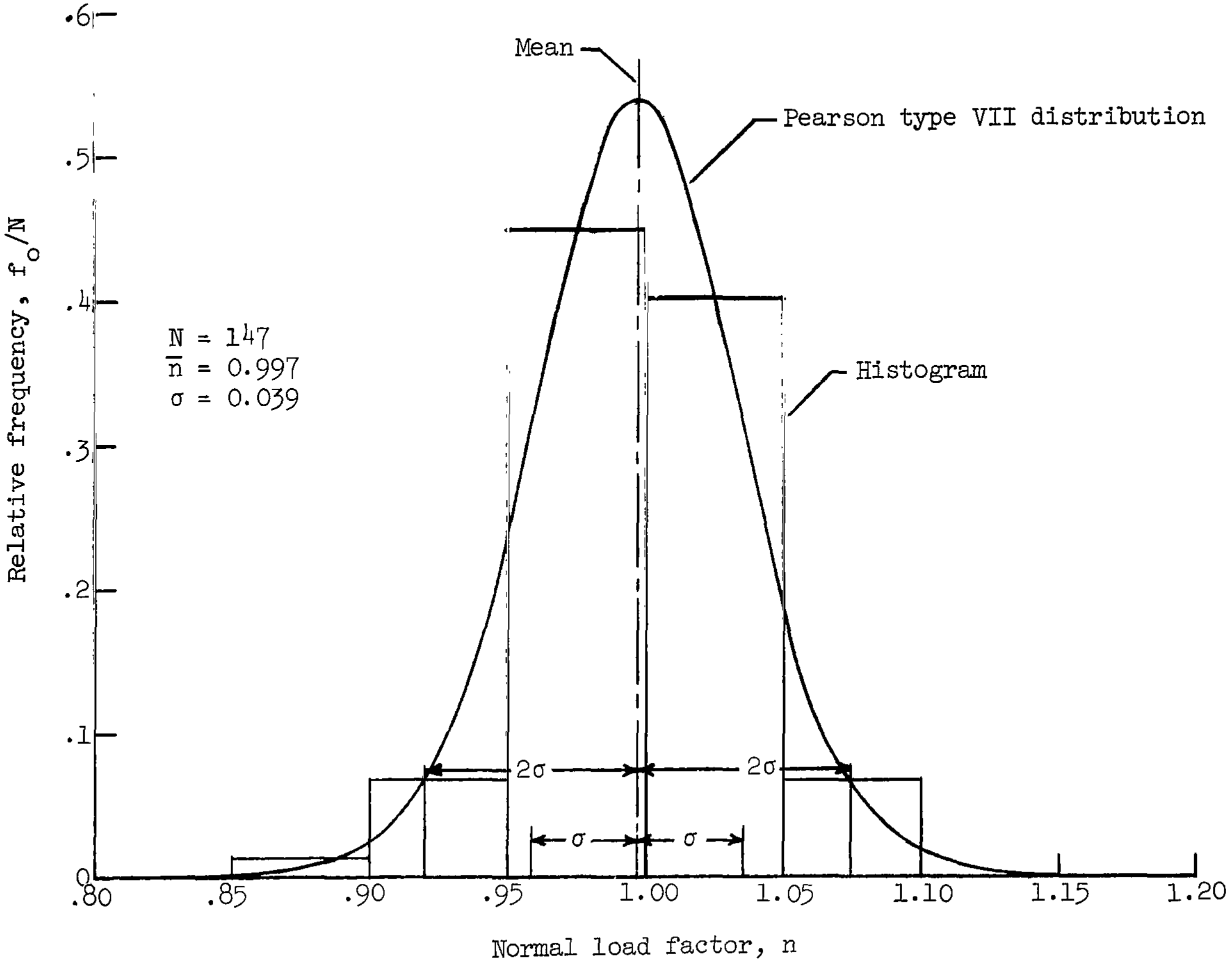
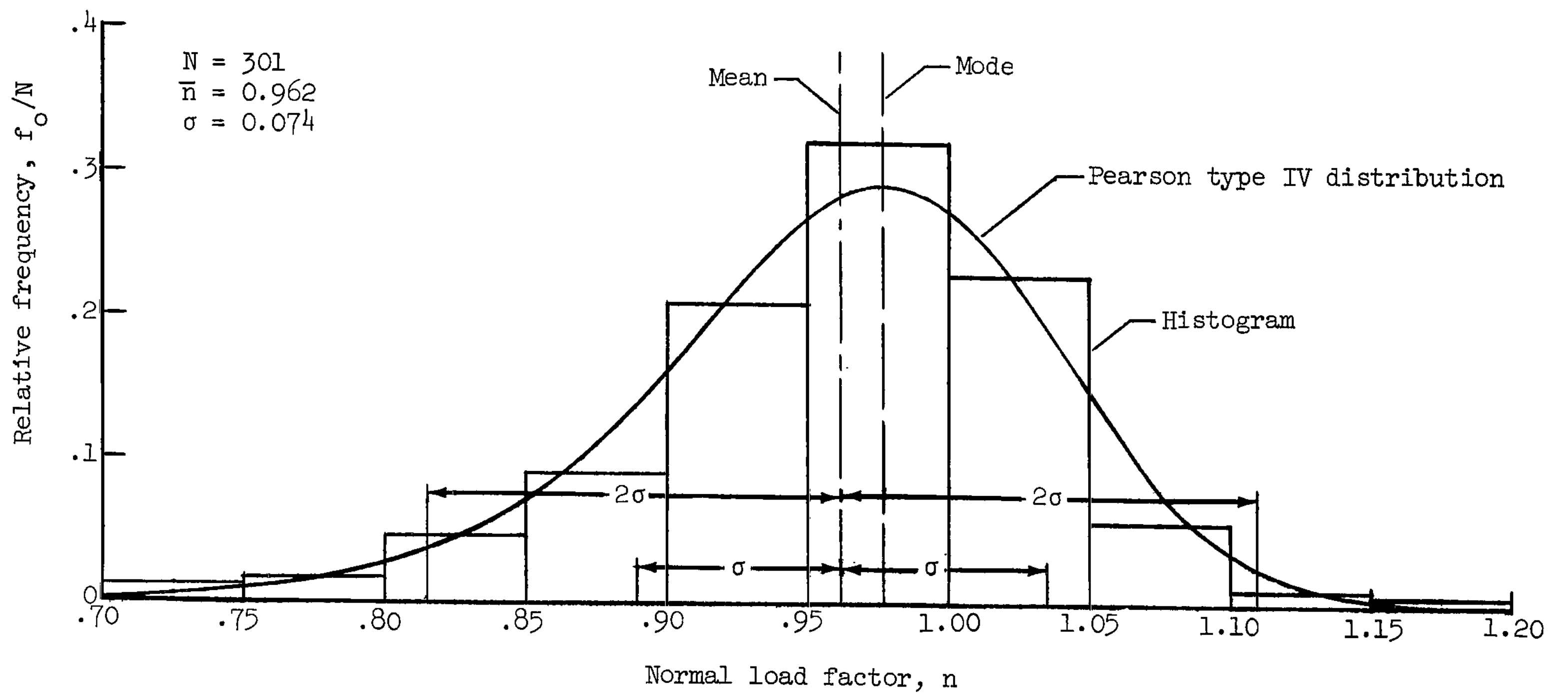


Figure 1.- Enlarged portion of VGH record for three landings.



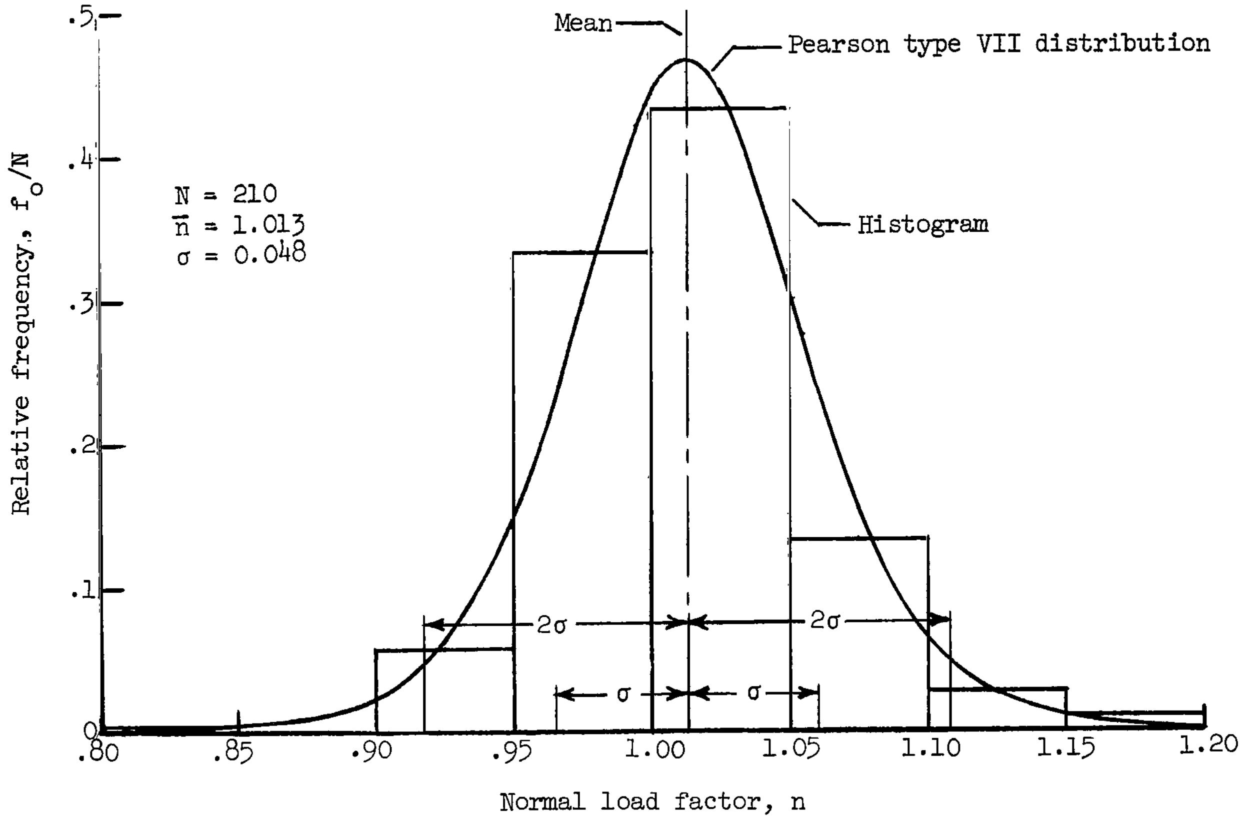
(a) Airplane A.

Figure 2.- Frequency distribution of normal load factor just prior to ground contact.



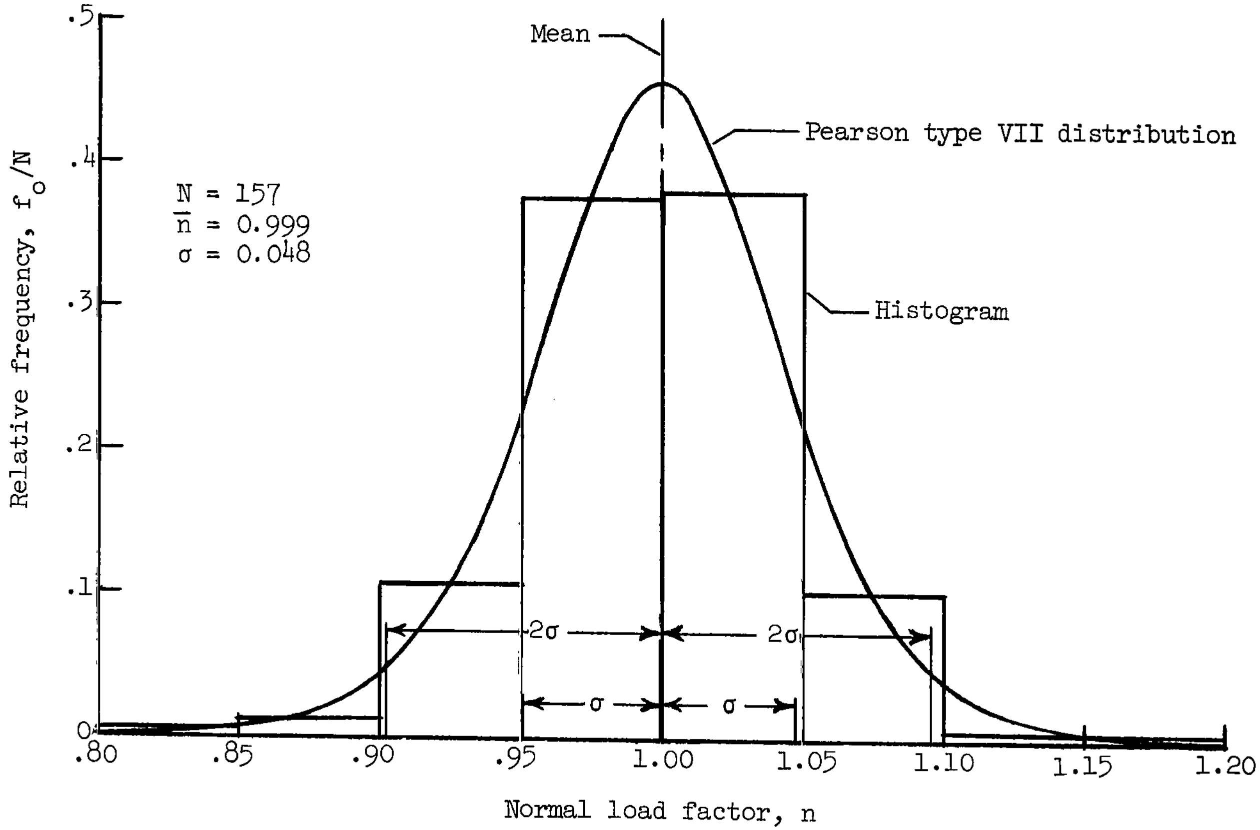
(b) Airplane B.

Figure 2.- Continued.



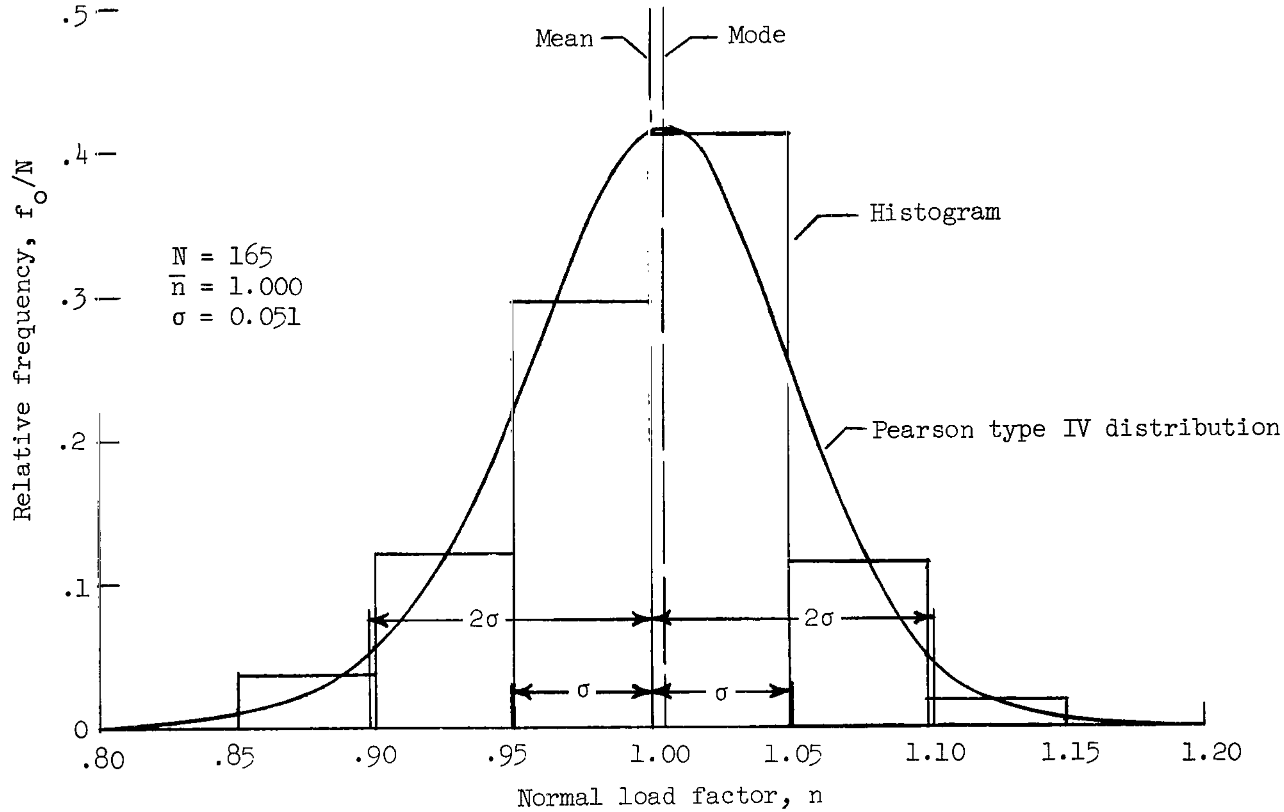
(c) Airplane C.

Figure 2.- Continued.



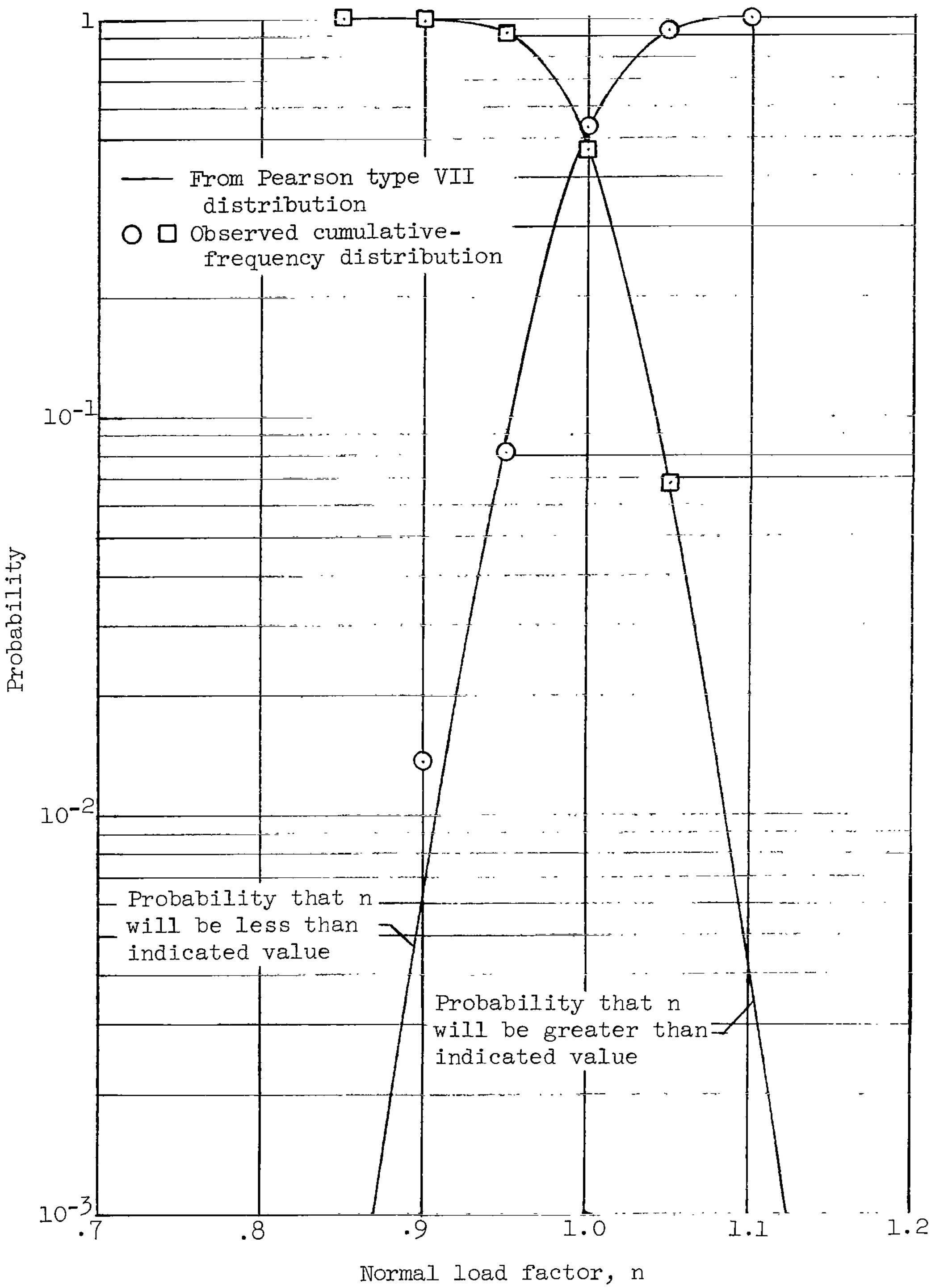
(d) Airplane D.

Figure 2.- Continued.



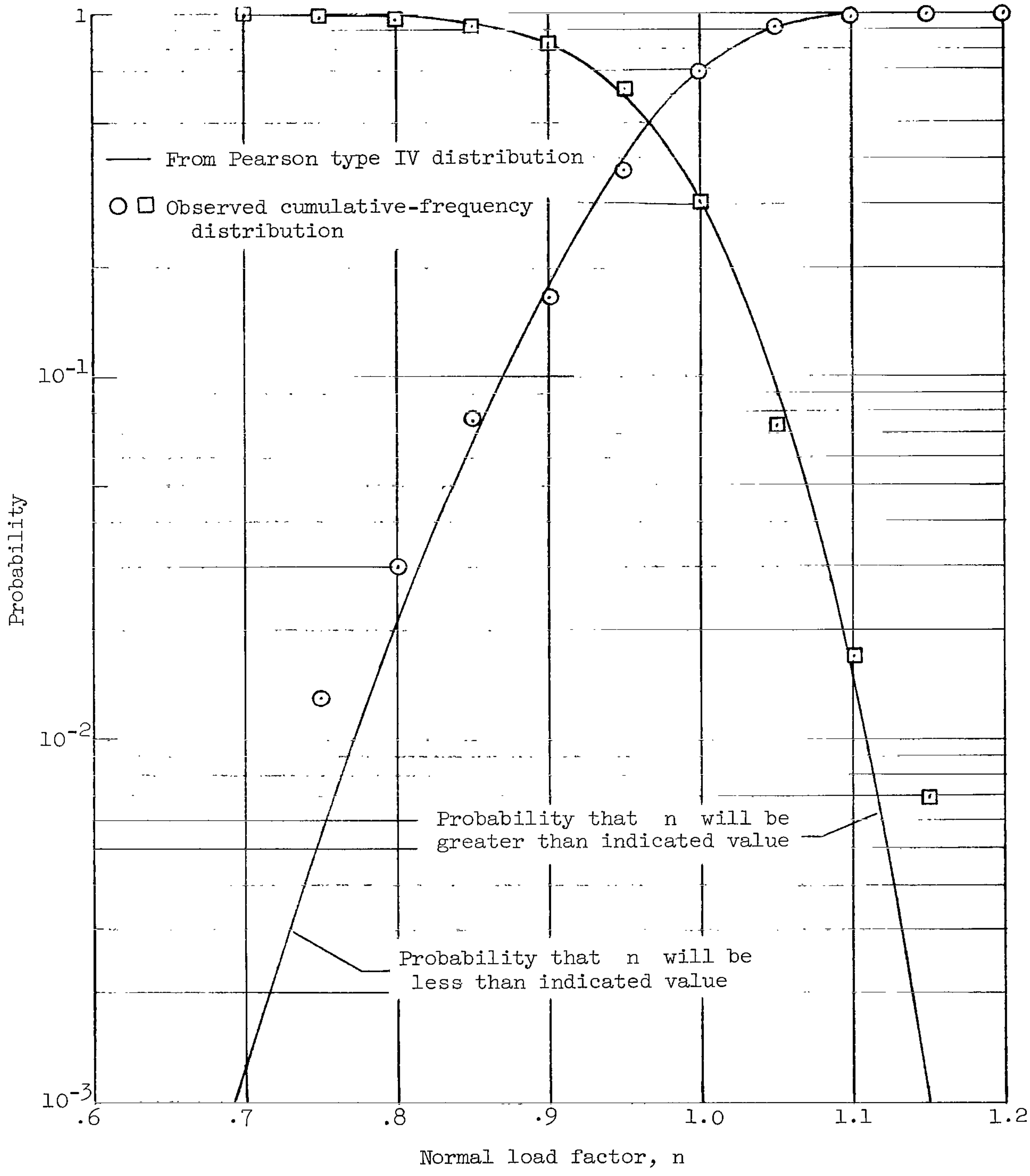
(e) Airplane E.

Figure 2.- Concluded.



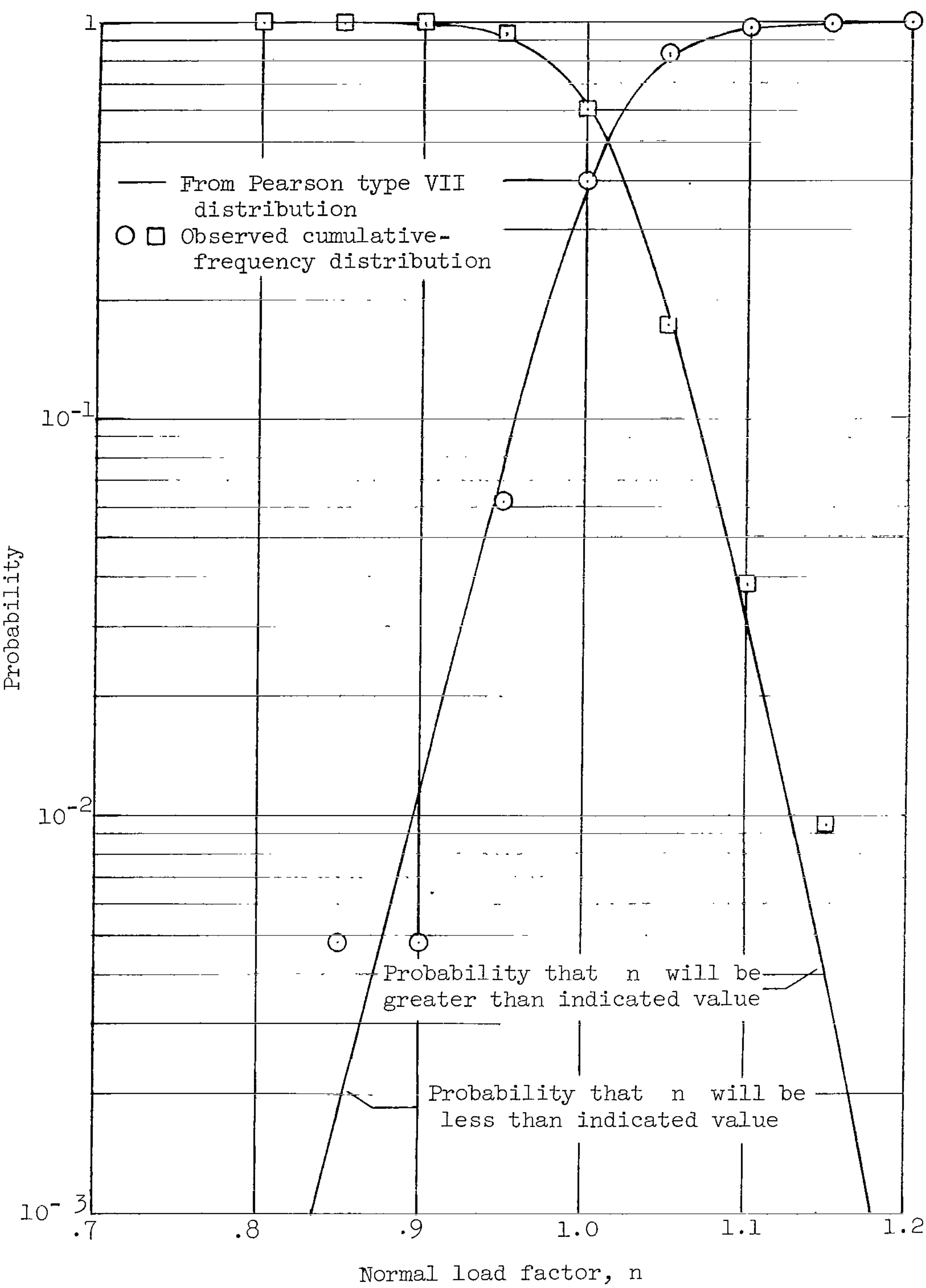
(a) Airplane A.

Figure 3.- Probability that airplane load factor just prior to ground contact will be greater than or less than indicated value.



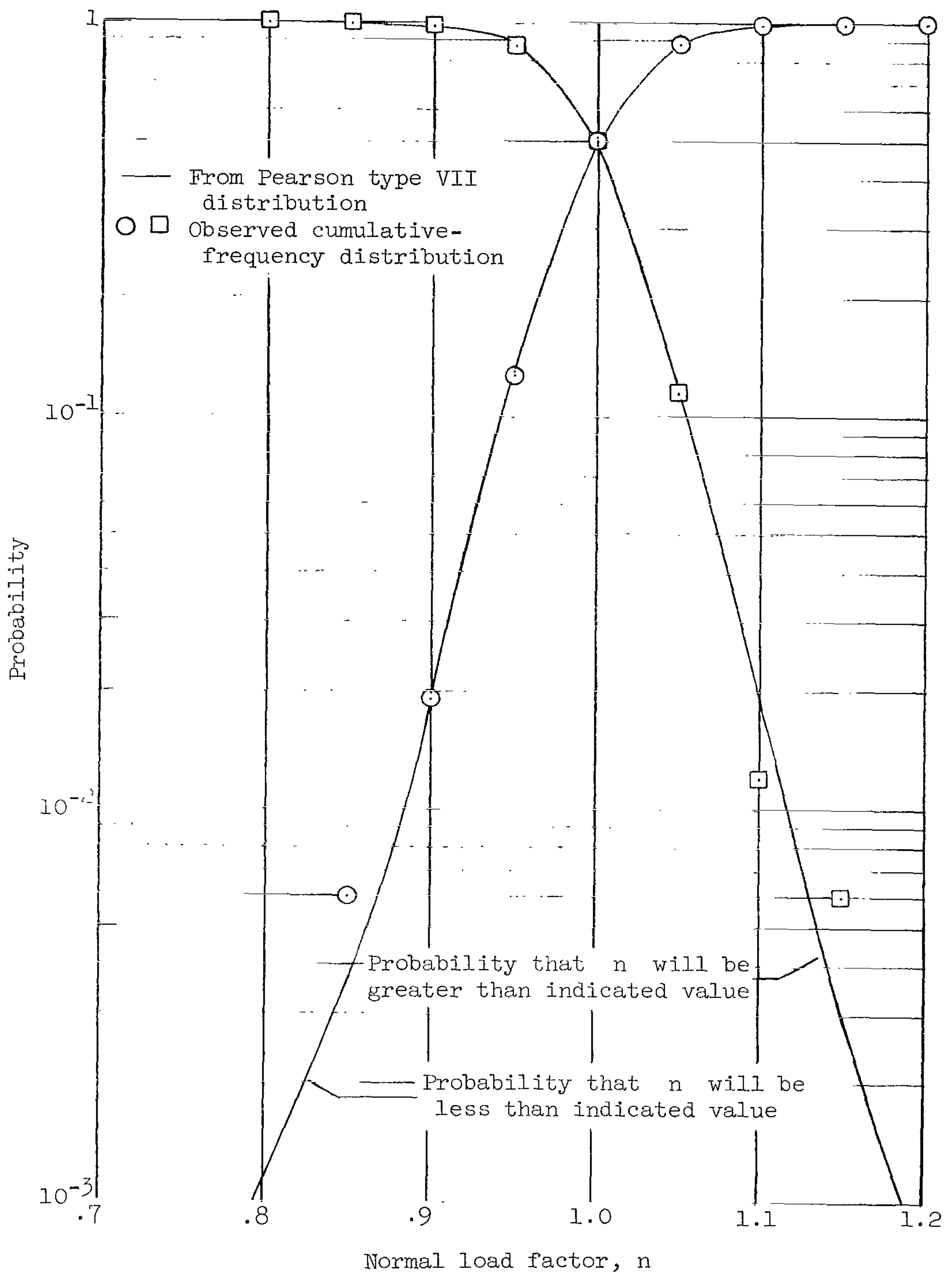
(b) Airplane B.

Figure 3.- Continued.



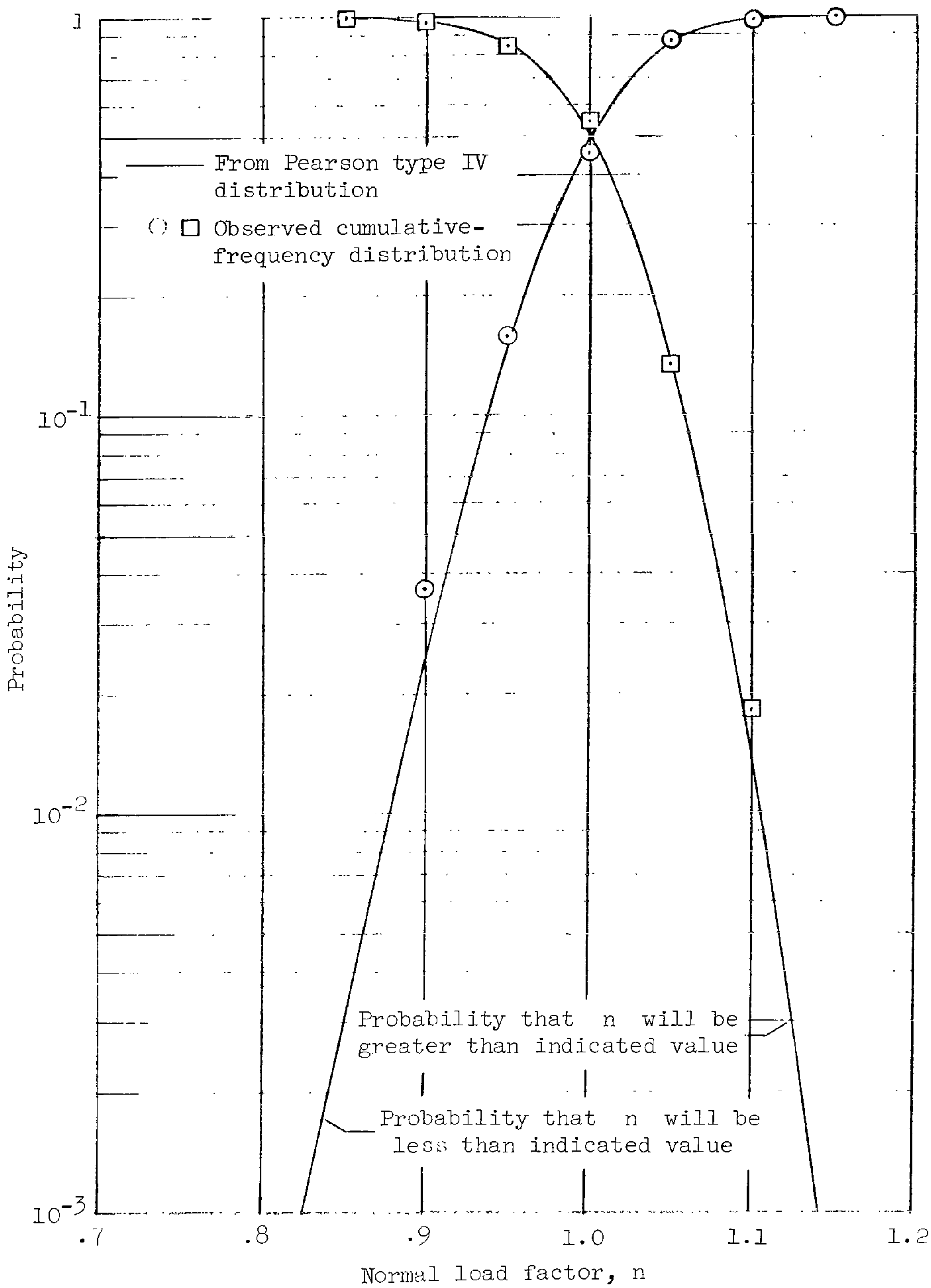
(c) Airplane C.

Figure 3.- Continued.



(d) Airplane D.

Figure 3.- Continued.



(e) Airplane E.

Figure 3.- Concluded.

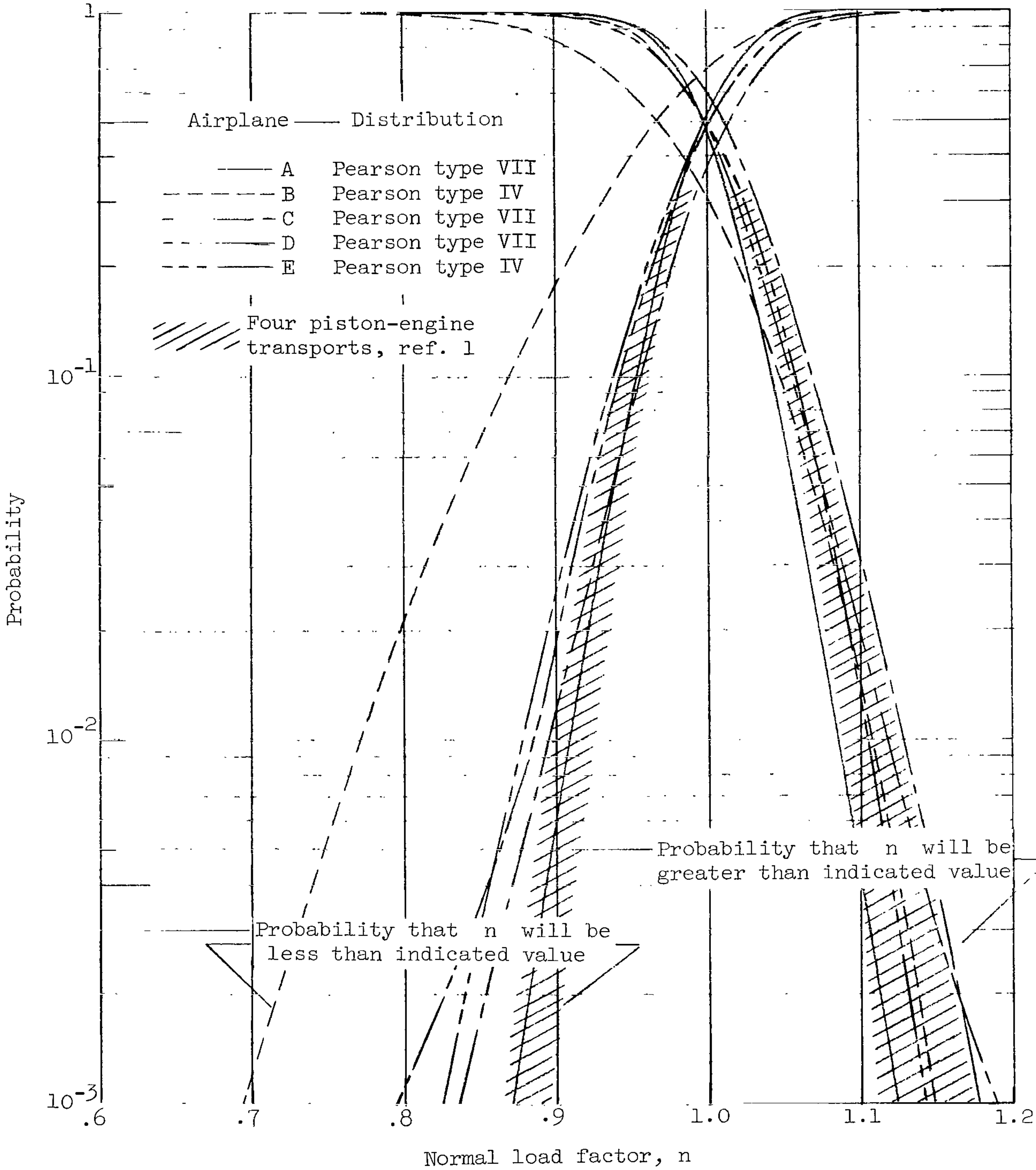


Figure 4.- Comparison of fitted probability curves for all samples of da .

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